Real World Connections

Baseball Hitter Hitting Ball

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When a player hits the baseball, the force of the ball on the bat is exactly the same as the force of the bat on the ball according to Newton's Third Law. Since the baseball has a smaller mass it flies off with a larger velocity than the bat which has a large mass and a small velocity. The Law of Conservation of Momentum is the basis for Newton's Third Law.

Universal Gravitation

Newton's Law of Universal Gravitation states that the force of attraction between any two point masses is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them. It can be illustrated by the following formula:

$$\mathbf{F_g = Gm_1m_2/r^2}$$

Where:

- $\mathbf{F_g}$ is the force between the two masses, measured in Newtons
- **G** is the Universal Gravitation Constant, $6.67 \times 10^{-11} \frac{N \bullet m^2}{kg^2}$
- m_1 and m_2 are masses, measured in kilograms
- **r** is the distance between the two masses, measured center to center in meters

The law indicates that there is a force of Earth pulling on the Moon and an equal and opposite force of the Moon pulling on Earth. Every object experiences this force of attraction, but when the masses are relatively small, the forces are also small. This law is limited to point or spherical masses with uniform mass distribution.

Example

Calculate the force of attraction between a 50. kg mass and a 3000. kg mass two meters apart.

Given:
- **G** = constant = 6.67×10^{-11} N m²/kg²
- $\mathbf{m_1}$ = 50. kg
- $\mathbf{m_2}$ = 3000. kg
- **r** = 2.0 m

Find: Force

Solution:

$$\mathbf{F_g = Gm_1m_2/r^2}$$
$$= (6.67 \times 10^{-11}\ N\ m^2/kg^2)(50.\ kg)(3000.\ kg)/(2.0\ m)^2$$
$$= 2.5 \times 10^{-6}\ N$$

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Tides

At the surface of Earth, Earth's force of gravitational attraction acts in a direction inward toward its center of mass, and thus holds the ocean water confined to this surface. However, the gravitational forces of the Moon and Sun also act externally upon Earth's ocean waters. These external forces are exerted as tide-producing forces. Their effects are superimposed upon Earth's gravitational force and act to draw the ocean waters to positions on Earth's surface directly beneath the Sun and the Moon. High tides are produced in the ocean waters by the "heaping" action resulting from the horizontal flow of water toward two regions of Earth representing positions of maximum attraction of combined lunar and solar gravitational forces. Low tides are created by a compensating maximum withdrawal of water from regions around Earth midway between these two humps. The alternation of high and low tides is caused by the daily rotation of Earth with respect to these two tidal humps and two tidal depressions.

Gravitational Fields

The concept of field was introduced by **Michael Faraday** to deal with the problems of forces acting at a distance. Every mass may be considered to be surrounded by a gravitational field. The interaction of the fields results in attraction. An object can push or pull you without touching you.

Mass measured by gravitational attraction is called **gravitational mass**. The most sensitive experiments possible to date conclude that gravitational mass is equivalent to inertial mass, and both are expressed in the same units.

The magnitude of the strength of a gravitational field at any point is the force per unit mass at that point in the gravitational field. The relationship:

$$\mathbf{g} = \mathbf{F_g}/\mathbf{m}$$

Where: **g** is the acceleration of gravity (in m/s^2)
$\mathbf{F_g}$ is the force (in Newtons)
m is the mass (in kilograms)

☆ TRY IT

The gravitational field at any planet can be calculated from the formula:

$$g = \frac{Gm}{r^2}$$

Where: **G** = universal gravitational constant
m = mass of planet
r = radius of planet

7 Using the constants from the *Reference Tables for Physical Setting/PHYSICS*, calculate ***g*** on Earth from this equation.

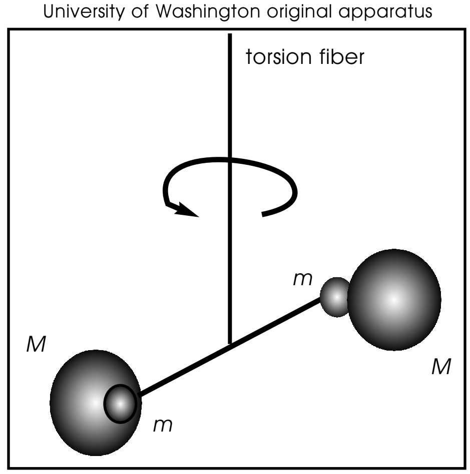
Note: The direction of the gravitational field is the direction of the force on a test mass. The force to mass ratio is the same for all objects.

REAL WORLD CONNECTIONS

MASSING THE EARTH?

It is a smaller world after all – that is, if new measurements by University of Washington physicists turn out to be correct. Their new calculations for the Earth's mass came from work that could establish the most precise measurement ever achieved of Isaac Newton's gravitational constant. The measurement of the planet's weight is derived from the gravitational attraction that Earth has for objects near it.

Rendition of
University of Washington original apparatus



Newton's gravitational constant allows us to calculate the gravitational force there is between two masses in newtons.

To make their measurements, the researchers are using a device called a torsion balance that records nearly imperceptible accelerations from the gravitational effects of four 8.14-kilogram stainless steel balls on a 3- by 1.5-inch gold-coated Pyrex plate just 1.5 millimeters thick. The device, operating inside an old cyclotron hall in the UW nuclear physics laboratory, is similar in nature to one used 200 years ago to make the first Big G measurement. However, it is computer controlled and contains numerous mechanical refinements that make the more precise measurement possible. These new findings will probably not affect the average person, but advance the frontiers of science.

So, what is the mass of planet Earth? The quick answer to that is: approximately 5,980,000,000,000,000,000,000,000 (5.98 x 10^{24}) kilograms.

WEIGHT

The weight of an object is equal to the net gravitational force acting on it. The weight of an object is equal to the product of its mass and the gravitational force.

$$F_g = mg$$

Where: F_g is weight in newtons
m is mass in kilograms
g is acceleration of gravity in m/s^2

Weight is a vector quantity that varies in magnitude with the location of the object with reference to the Earth. Spring scales may be used in weight measurements, but comparison of masses ("weighing") on a balance should be referred to as measurement of mass. To one significant figure, 100 grams has a weight of one newton. The average apple has a weight of one newton. Kilograms and grams are commonly misused as if they were weight units, especially on grocery package labeling.

REAL WORLD CONNECTIONS

WORLD TRADE CENTER – 11 SEPTEMBER 2001

[Publisher's Note: On 11 September 2001, four U.S. planes hijacked by terrorists crashed in New York, Washington, and Pennsylvania killing more than 3,000 people. It is important that all of us remember the tragic human loss, because in so doing, we honor the memory of the victims and heroes of that dark day in U.S. history. It is also necessary that we study the physics of the destruction, as hopefully with research and understanding, engineering to prevent this kind of tragedy will be discovered and implemented.]

The World Trade Center "twin towers" were completed in 1970 as state of the art buildings designed with one of the earliest applications of computer stress analysis. The foundations extended more than 70 feet into the ground, resting on solid bedrock. 200,000 tons of steel and 425,000 cubic yards of concrete were used to build the towers. They were some of the best examples of "tube buildings," with closely spaced columns and beams in the outer walls, designed to withstand hurricane winds, fire, and the impact of an airplane. Even the sky lobby elevators could hold 10,000 pounds each. So, what caused the collapse of the Twin Towers?

Photo: Garnsey